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IN THE EUROPEAN PATENT OFFICE

Applicant:	Photon Control Inc.
Title:	OPTICAL DEVICE AND METHOD FOR SENSING MULTIPHASE FLOW
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To: The Canadian Intellectual Property Office
(International Preliminary Examining Authority)
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ARTICLE 34 AMENDMENT

Responsive to the written opinion mailed 16 March 2005, please substitute the enclosed replacement sheets numbered 17 and 20-26 for the correspondingly numbered sheets of this application.

Former claims 1 to 21 have been replaced with the enclosed claims 1 to 19. Claims 1, 8 (formerly 9), 14 (formerly 16) and 17 (formerly 19) have been amended.

Claims 2-7, 10-13, 15-16 and 18-19 have been renumbered but otherwise remain unchanged.

Re: Box No. V

Previously pending claim 1 has been amended to incorporate the step of passing the signals through a plurality of band pass filters recited in previously pending claim 2. Likewise, previously pending claim 9 has been amended to incorporate the band pass filters recited in previously pending claim 10. Accordingly, previously pending claims 2 and 10 have been cancelled, previously pending claims 3 to 8 have been renumbered as claims 2 to 7, and previously pending claims 9 and 11 to 21 have been renumbered as claims 8 to 19.

Document D1 discloses a gas velocity meter comprising a correlator (16) having two high pass filters (29, 30) for processing signals received from two photodetectors (14, 15). The

high pass filters separate out a "constant component" of the signals. (See column 4, lines 44-65 and Figure 4.)

Document D2 discloses a method and apparatus for measuring flow velocity using matched filters. At each of two locations, a liquid matched filter (24, 26) and a gas matched filter (34, 36) are coupled to an amplifier (18, 20) which receives signals from a probe (10, 12). The matched filters comprise RC low pass filters. (See column 5, lines 12-15 and Figure 5.)

Document D3 discloses a method and system for measuring physical properties of flows or currents, wherein at least three sensor heads are used to produce measuring signals. There is no discussion in document D3 of any filtering of the measuring signals.

Document D4 discloses a technique for simultaneously measuring two velocity components and one or more physical properties of particles passing through two separated beams of radiation. The only filters disclosed by document D4 are density filters (see column 3, lines 60-63) and optical filters (see column 4, lines 8-9).

None of the references cited in the written opinion teaches or suggests a method for measuring the velocity of a multiphase fluid wherein a pair of signals are passed through a plurality of band-pass filters, as recited in amended claim 1. Likewise, none of the prior art cited in the written opinion teaches or suggests an apparatus for measuring the velocity of a multiphase fluid comprising a plurality of band-pass filters, as recited in amended claim 8. The use of band pass filters allows a plurality of pairs of frequency components to be isolated from the pair of signals.

Accordingly, it is submitted that amended claims 1 and 8, as well as claims 2-7 and 9-13 which depend therefrom, are patentable over the cited references.

Re: Box No. VII

The Examiner pointed out that page 17, line 20 of the description refers to a steam quality of "56%", whereas Figure 14B shows as steam quality of "65%". Page 17, line 20 of the description has been amended to correct this discrepancy.

Re: Box No. VIII

The Examiner stated that "[i]t is not clear from the disclosure what the distinction is between scattered and deflected light." The Applicant submits that, to a person skilled in the art, "deflected" light refers to light which has been refracted, and "scattered" light refers to light

which has been reflected. Accordingly, deflected light travels in a direction which is governed by Snell's law, while scattered light can travel in any direction, with an intensity which depends on the scattering angle.

The Examiner also stated that "[i]t is not clear in the claims if the multi phase fluid is Liquid/Gas, Liquid/Solid, Gas/Solid or a combination of all three." The claims have been amended to recite that the multiphase fluid has a liquid phase and a gaseous or solid phase.

Pursuant to Rule 66.4(b) the Applicant respectfully requests that it be given one or more additional opportunities to submit amendments and/or arguments, should the amendments and/or arguments presented herein be deemed insufficient to overcome all objections raised by the International Preliminary Examining Authority.

Respectfully submitted,
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avalanche photodiodes (APD) as photodetectors 214, 216 if steam quality is approaching 100% or steam is superheated.

[0039] Light sheets 202, 204 may be provided at various locations within pipe 16. The sheets can be located in the center of the pipe, with the centerline velocity being measured using the cross-correlation technique. The centerline velocity must be converted into average velocity in order to calculate the total flow of the fluid. This conversion can be done by calculating the Reynolds number through known temperature and pressure of the fluid. Alternatively, the sheets can be located at ¼ radius from the pipe wall. This location eliminates the need for velocity conversion because the measured velocity at this point represents the integral velocity along pipe 16.

[0040] In addition to determining the flow velocity through cross-correlation calculation, the signal processing means for this embodiment may be used to calculate dispersion of the signals from photodetectors 214, 216. Figure 14A and Figure 14B show the signal from one of the photodetectors while monitoring steam moving at a speed of 20m/s and having a quality of 94% and 65%, respectively. Higher water content or lower steam quality resulted in increasing the signal dispersion from 0.52 to 0.97 in this example.

[0041] According to yet another embodiment, a collimated beam 230 is added to two light sheets as shown in Figure 15. The two light sheets are used to determine the flow velocity in a way as described above. Light from the collimated beam 230 is attenuated by the fluid flowing in pipe 16, and it is collected by an optical system 232 into a reference photodetector 234. In addition to velocity measurement using the cross-correlation technique, the signal processing means for this embodiment may be used to calculate dispersion of the signal from

WHAT IS CLAIMED IS:

1. A method for measuring the velocity of a multiphase fluid flowing in a pipe, the multiphase fluid comprising a liquid phase and a gaseous or solid phase, the method comprising:
   a. directing a pair of collimated beams of light from an illuminator through the multiphase fluid by means of transparent portions of the pipe, said pair of collimated beams spaced apart in a direction of flow of the multiphase fluid by a predetermined distance;
   b. detecting scattered, deflected and attenuated light with a pair of photodetectors to produce a pair of signals, each of said pair of photodetectors associated with one of said pair of collimated beams;
   c. calculating a cross-correlation function between said pair of signals to determine a time delay between the signals;
   d. calculating the average velocity of the multiphase fluid by taking the ratio of the predetermined distance to the time delay between the signals; and,
   e. passing the pair of signals through a plurality of band-pass filters to isolate a plurality of pairs of corresponding frequency components, each of the plurality of pairs of corresponding frequency components corresponding to one of a plurality of flow components.

2. A method according to claim 1 further comprising, for each of said plurality of pairs of corresponding frequency components:
   a. calculating a cross-correlation function between the pair of corresponding frequency components to determine a time delay between the corresponding frequency components; and,
   b. calculating the velocity of the corresponding flow component by taking the ratio of the predetermined distance to the time delay between the corresponding frequency components.

3. A method according to claim 2 further comprising determining an intensity of each of said pairs frequency components and calculating an amount of a corresponding one of said plurality of flow components from said intensity.

4. A method according to claim 3 further comprising determining a flow rate of each of said plurality of flow components by multiplying the velocity of each flow component by the intensity of the corresponding pair of frequency components.

5. A method according to claim 4 wherein a vapour fraction of said multiphase flow is calculated as a flow rate of a fastest one of said plurality of flow components.

6. A method according to claim 5 further comprising determining a total flow rate of said multiphase flow by summing the flow rates of all of said plurality of flow components.

7. A method according to claim 6 further comprising calculating a quality of the multiphase flow by taking a ratio of the vapour fraction to the total flow rate.

8. An apparatus for measuring the velocity of a multiphase fluid flowing in a pipe, the multiphase fluid comprising a liquid phase and a gaseous or solid phase, the apparatus comprising:

   a. an illuminator for generating a pair of collimated beams of light and directing said beams through the multiphase fluid by means of transparent portions of the pipe, said pair of collimated beams spaced apart in a direction of flow of the multiphase fluid by a predetermined distance;

   b. a pair of photodetectors positioned across the pipe from said illuminator, each of said pair of photodetectors optically associated

with one of said pair of collimated beams for detecting scattered, deflected and attenuated light from the associated beam and generating a signal; and,

c. a signal processing means for processing the signals from said pair of photodetectors and calculating cross-correlation functions between the signals to determine a time delay, and for calculating the velocity of the multiphase fluid by taking a ratio of the predetermined distance to the time delay, said signal processing means comprising a plurality of band-pass filters for isolating a plurality of frequency components of each of the pair of signals.

9. An apparatus according to claim 8 wherein said illuminator comprises a first illuminator for generating a first pair of collimated beams, and wherein said pair of photodetectors comprises a first pair of photodetectors, the apparatus further comprising:

a. a second illuminator for generating a second pair of collimated beams of light and directing said second pair of beams through the multiphase fluid at an angle to said pair of beams generated by said first illuminator; and,

b. a second pair of photodetectors positioned across the pipe from said second illuminator, each of said second set pair of photodetectors optically associated with one of said second pair of collimated beams for detecting scattered, deflected and attenuated light from the associated beam and generating a signal,

wherein said signals from said second pair of photodetectors are processed by said signal processing means.

10. An apparatus according to claim 9 wherein the angle is perpendicular.

11. An apparatus according to claim 9 further comprising at least one optical system for focusing light scattered at a near perpendicular angle from said

pair of collimated beams from at least one measurement zone onto at least one photodetector.

12. An apparatus according to claim 8 further comprising a multi-focal optical system for focusing light scattered at a shallow angle from said pair of collimated beams from a plurality of measurement zones onto a plurality of photodetectors.

13. An apparatus according to claim 8 further comprising a multi-focal optical system for focusing light scattered at a near 180 degree angle from said pair of collimated beams from a plurality of measurement zones onto a plurality of photodetectors.

14. A method for measuring the velocity of a multiphase fluid flowing in a pipe, the multiphase fluid comprising a liquid phase and a gaseous or solid phase, the method comprising:

(a) directing a pair of light sheets from an illuminator through the multiphase fluid by means of transparent portions of the pipe, said pair of light sheets oriented perpendicular to a direction of flow of multiphase fluid and spaced apart in the direction of flow by a predetermined distance;

(b) detecting scattered and deflected light with a pair of photodetectors to produce a pair of signals, each of said pair of photodetectors associated with one of said pair of light sheets;

(c) calculating a cross-correlation function between said pair of signals to determine a time delay between the signals;

(d) calculating the average velocity of the multiphase fluid by taking the ratio of the predetermined distance to the time delay; and

(e) calculating an amount of liquid fraction in the multiphase fluid based on dispersion of signals from said photodetectors.

15. A method according to claim 14 further comprising:
   (a) directing at least one collimated beam in a direction generally parallel to said pair of light sheets;
   (b) detecting deflected and attenuated light from said collimated beam with a reference photodetector to produce a signal associated with said collimated beam; and,
   (c) calculating the amount of liquid fraction in the multiphase fluid based on dispersion of the signal from said reference photodetector.

16. A method according to claim 14 further comprising:
   (a) directing at least one collimated beam in a direction generally parallel to said pair of light sheets, said collimated beam comprising light of a first wavelength with high absorbance in a liquid fraction and light of a second wavelength with low absorbance in the liquid fraction;
   (b) detecting attenuated light with reference photodetectors to produce a first signal corresponding to light of said first wavelength and a second signal corresponding to light of said second wavelength; and,
   (c) calculating the amount of liquid fraction in the multiphase fluid based on a ratio of said first and second signals.

17. An apparatus for measuring the velocity of a multiphase fluid flowing in a pipe, the multiphase fluid comprising a liquid phase and a gaseous or solid phase, the apparatus comprising:
   (a) an illuminator for generating a pair of light sheets and directing said light sheets through the multiphase fluid by means of transparent portions of the pipe, said pair of light sheets oriented perpendicular to a direction of flow of multiphase fluid and spaced apart in the direction of flow by a predetermined distance;
   (b) a pair of photodetectors positioned across the pipe from said illuminator, each of said pair of photodetectors optically associated

with one of said light sheets for detecting scattered light from the associated light sheet and generating a signal; and,

(c) a signal processing means for processing the signals form said pair of photodetectors, calculating cross-correlation functions between the signals to determine a time delay, calculating the velocity of the multiphase fluid by taking a ratio of the predetermined distance to the time delay, and for calculating an amount of liquid fraction in the multiphase fluid based on dispersion of signals from said photodetectors.

18. An apparatus according to claim 17 further comprising:

(a) a reference illuminator for generating a collimated beam and directing said collimated beam through the multiphase fluid by means of transparent portions of the pipe;

(b) a reference photodetector positioned across the pipe from said reference illuminator and optically associated with said collimated beam for detecting attenuated light from said collimated beam and generating a signal, and;

(c) a reference signal processing means for processing said signal from said reference photodetector and calculating the amount of liquid fraction in the multiphase fluid based on dispersion of said signal.

19. An apparatus according to claim 17 further comprising:

(a) a reference illuminator for generating a collimated beam and directing said collimated beam through the multiphase fluid by means of transparent portions of the pipe, said collimated beam comprising light of a first wavelength with high absorbance in a liquid fraction and light of a second wavelength with low absorbance in the liquid fraction;

(b) reference photodetectors positioned across the pipe from said illuminator and optically associated with said collimated beam for

detecting attenuated light from said collimated beam and generating a first signal corresponding to light of said first wavelength and a second signal corresponding to light of said second wavelength, and;

(c) a reference signal processing means for processing said first and second signals and calculating the amount of liquid fraction in the multiphase fluid based on a ratio of said first and second signals.